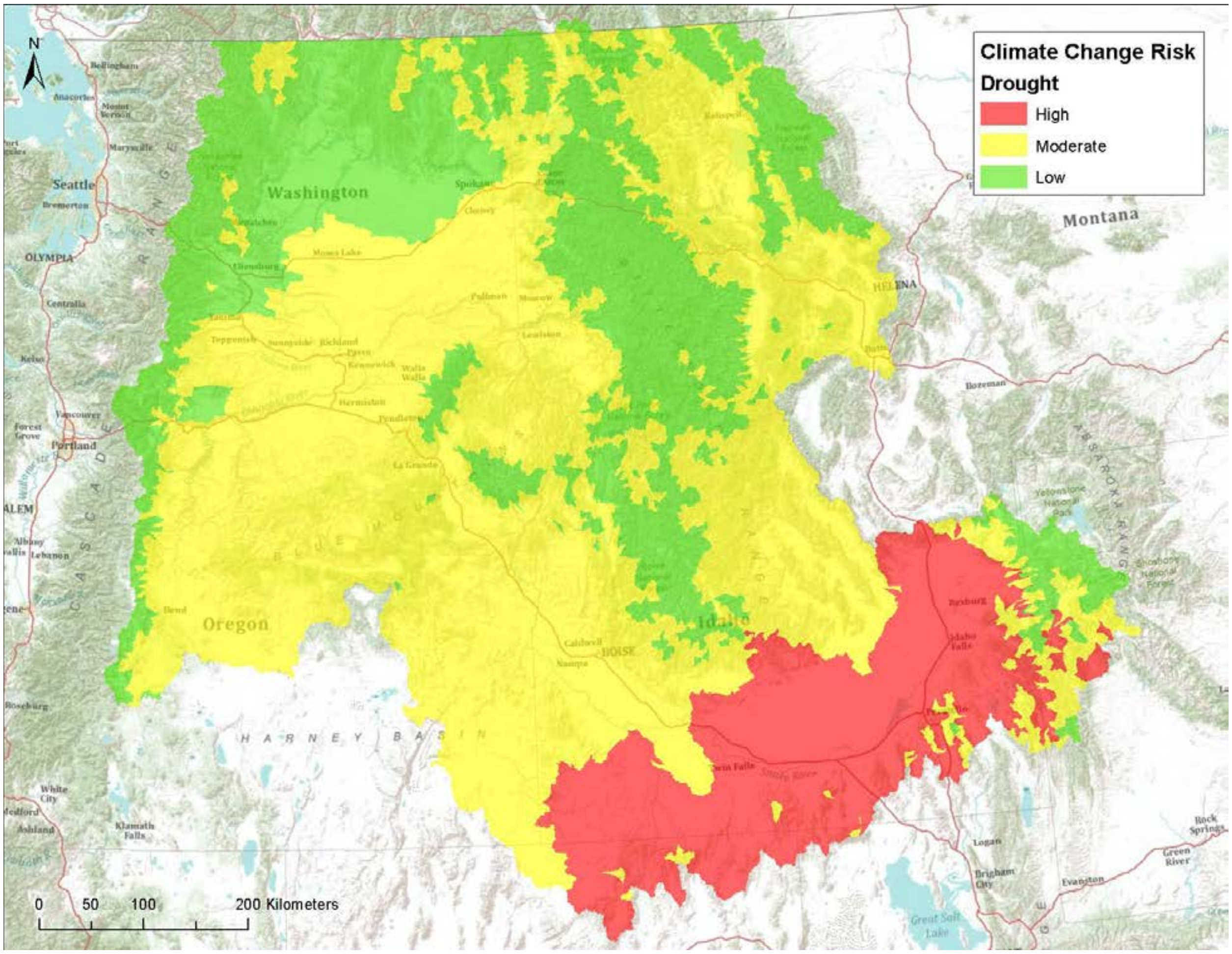
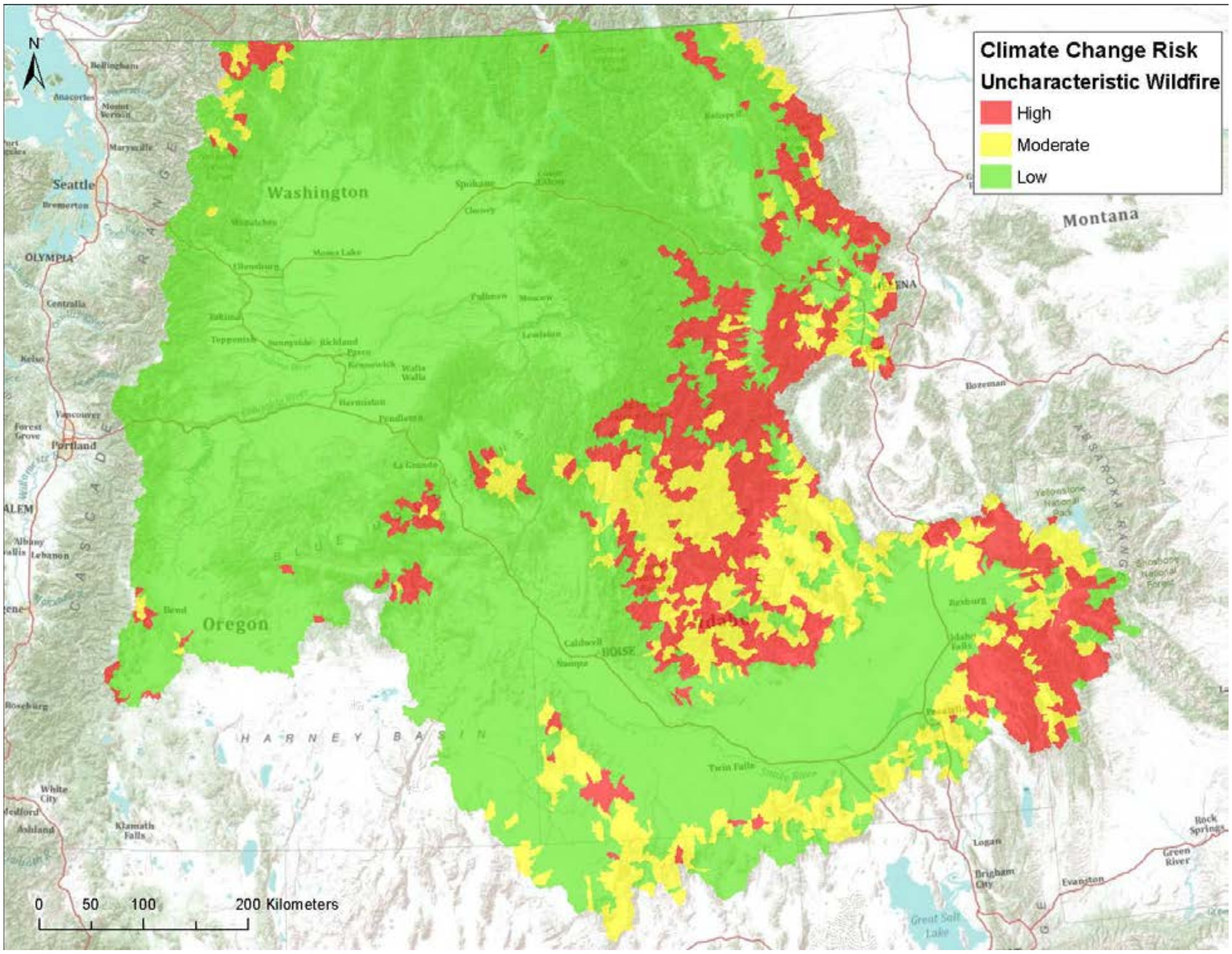
Conservation Success Index: Interior Columbia Wild Trout

Rev. 1.0 - 9/2011

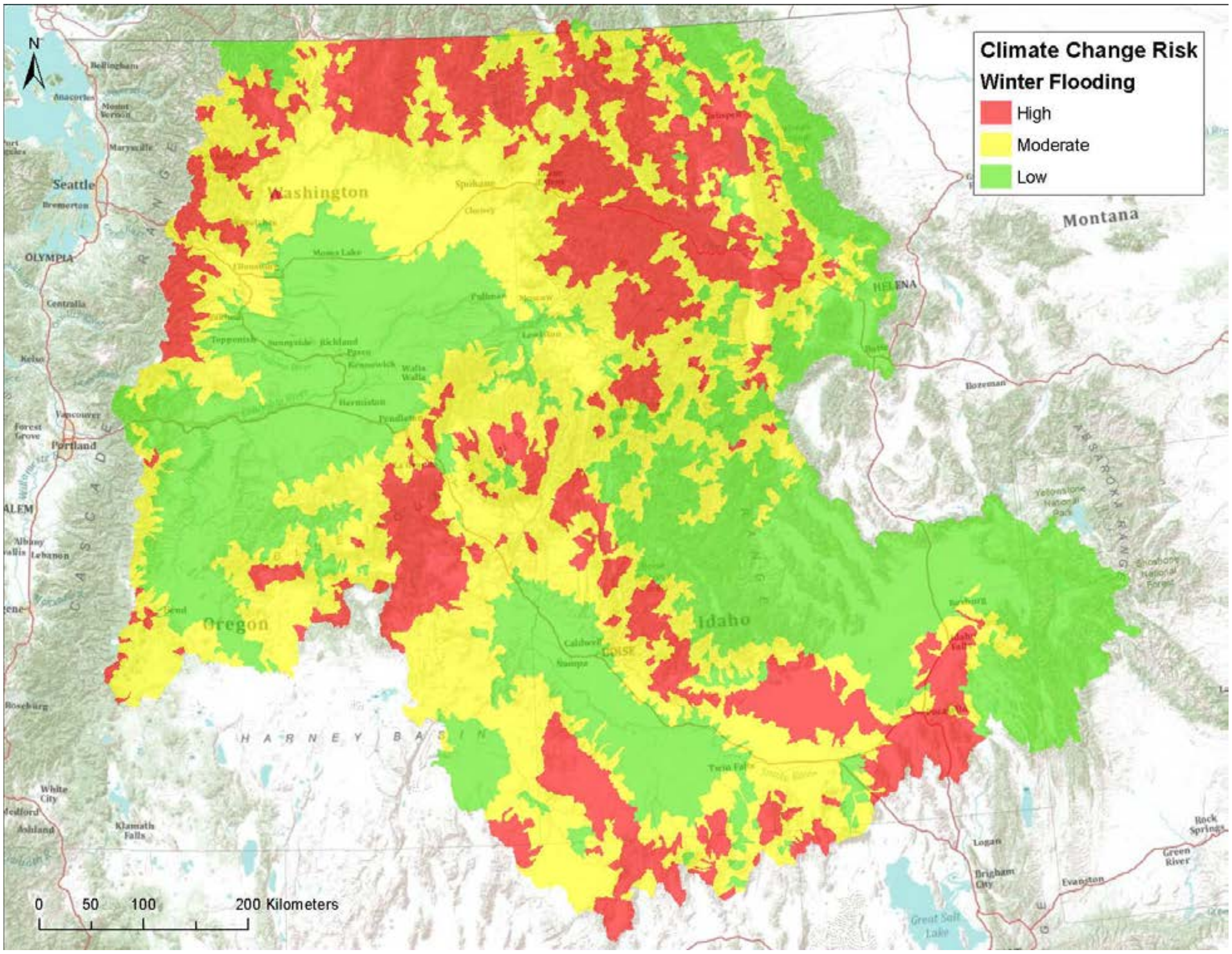
SPECIES SUMMARY

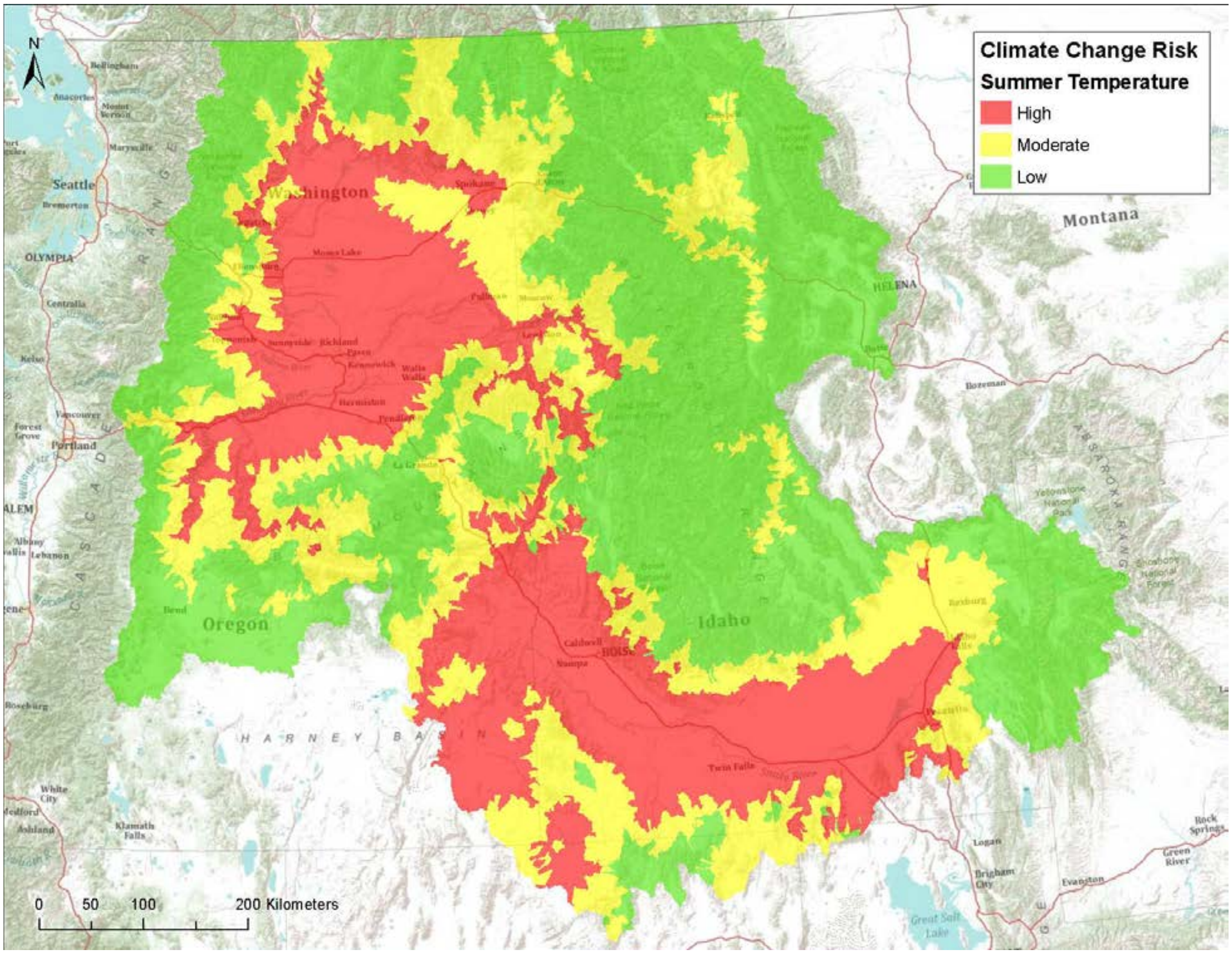
Trout Unlimited's mission is to protect, reconnect, restore and sustain coldwater habitats and fisheries across the country. Historically, the United States had a plethora of coldwater resources, but over time they have been impacted by land uses, water uses, pollutants, and other factors. Native trout fisheries have also declined due to overharvest and introduction of non-native species. Good coldwater conservation decisions are made using reliable information describing habitat conditions and future threats both across large geographic areas as well as within individual subwatersheds. This wild trout CSI is intended to inform conservation decision at the subwatershed (~30,000 acre) scale by conveying information about the amount of coldwater and native trout resources, along with information on factors known to influence coldwater habitats and threaten their future security. Wild trout CSI information can be used to inform conservation decisions that are subsequently refined through review of finer-scale information and discussions with project partners to ensure coldwater fisheries persist and can be enjoyed by future generations of anglers.


Climate Change Risk
Drought
High
Moderate
Low
Washington
Oregon
Idaho
Montana
Seattle
Portland
Spokane
HELENA
BOISE
HARNEY BASIN
0 50 100 200 Kilometers

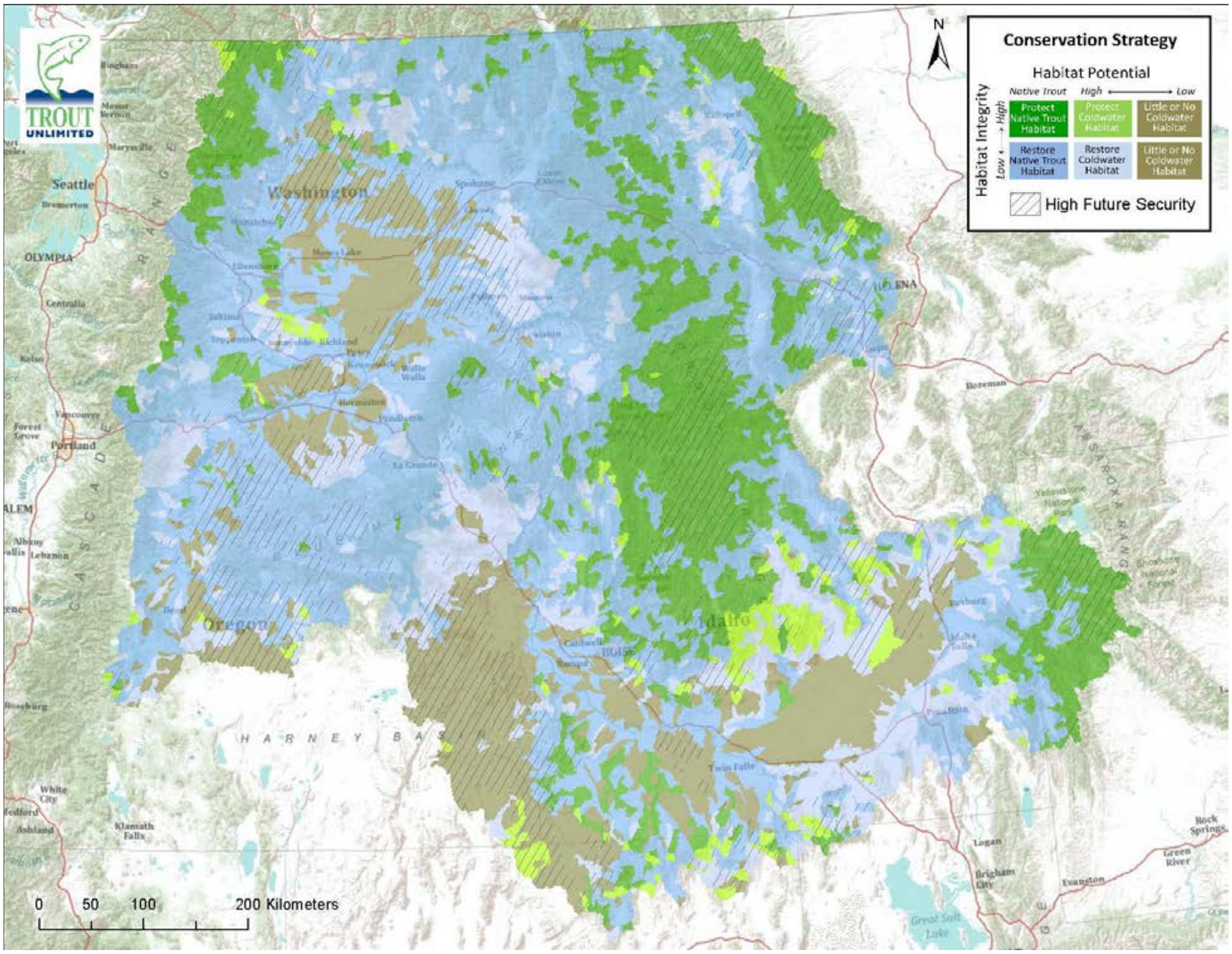


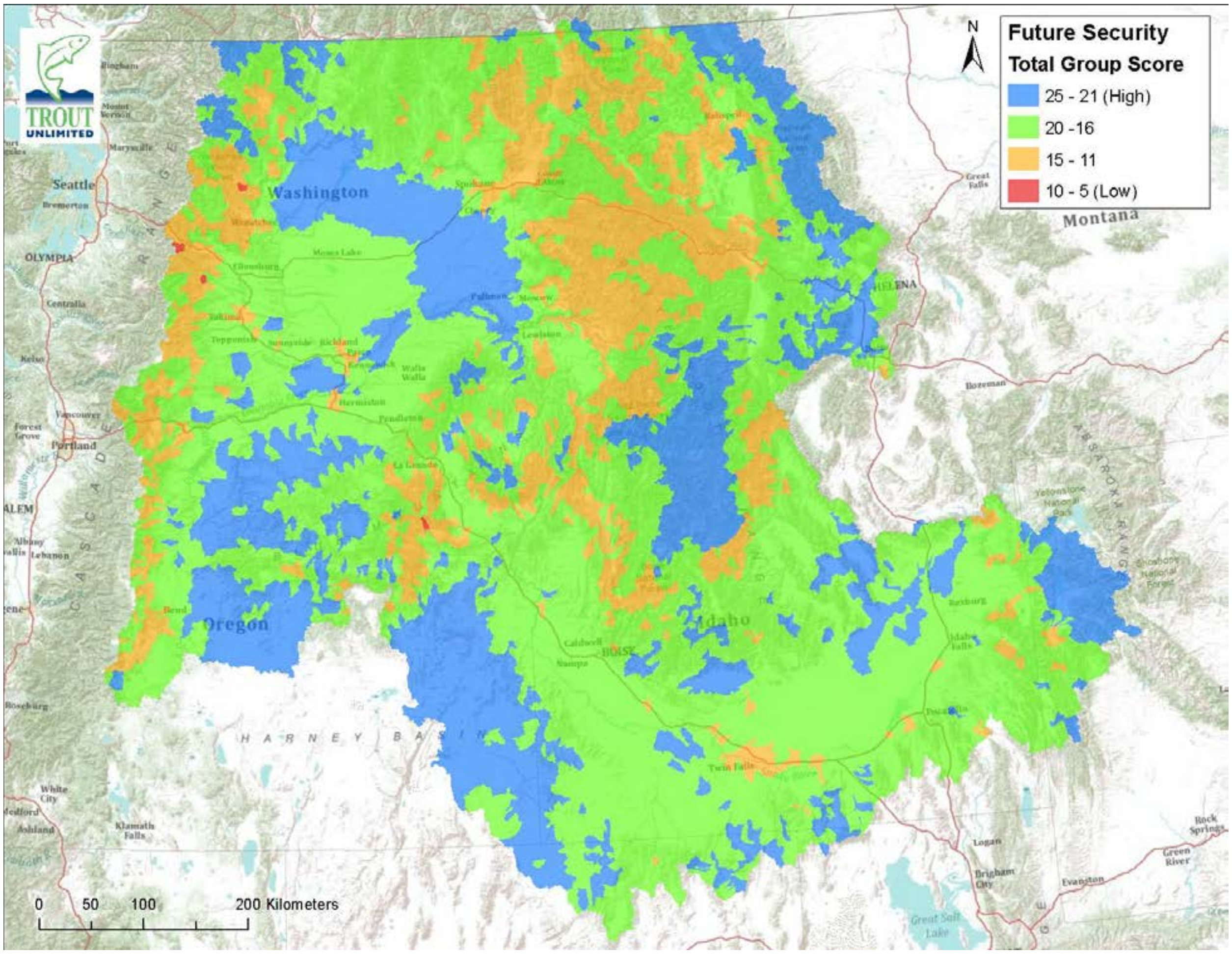
Climate Change Risk
Uncharacteristic Wildfire
High
Moderate
Low
N
0 50 100 200 Kilometers
Washington
Oregon
Montana
Seattle
Portland
OLYMPIA
Spokane
Boise
Twin Falls
Bozeman
Logan
H A R N E Y B A S I N

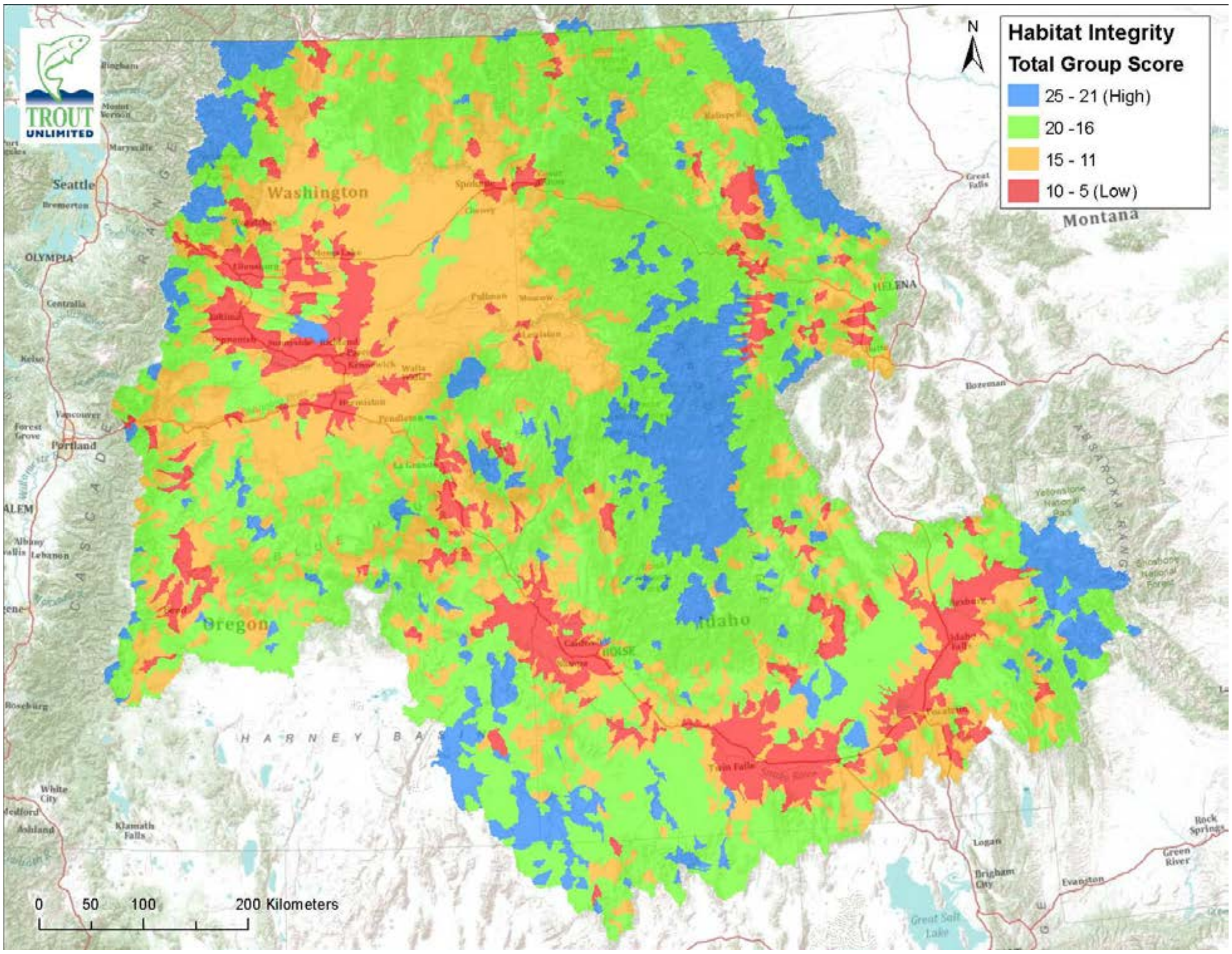

Climate Change Risk
Winter Flooding
High
Moderate
Low
0 50 100 200 Kilometers

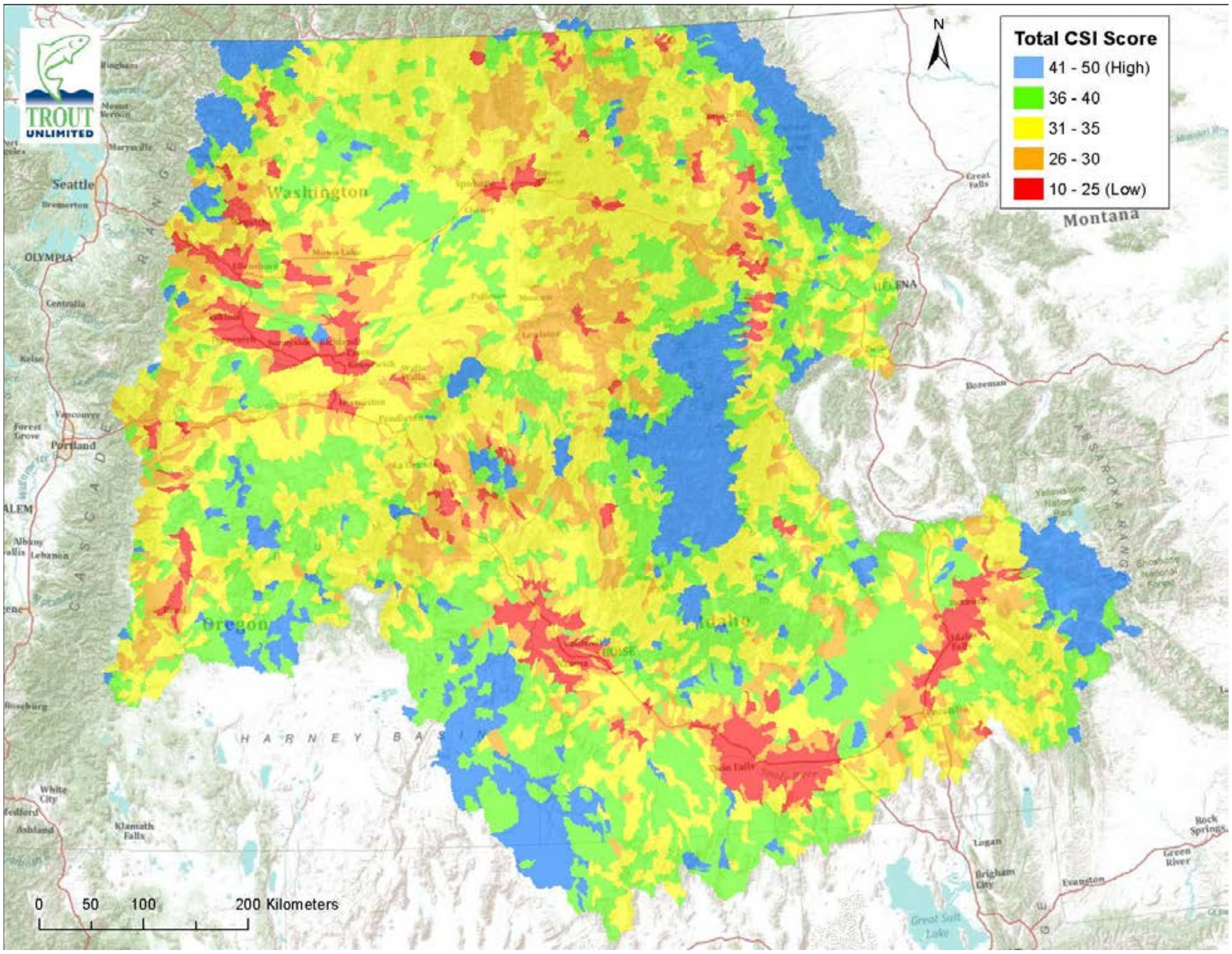


Climate Change Risk
Summer Temperature
High
Moderate
Low
0 50 100 200 Kilometers
Washington
Oregon
Idaho
Montana


Conservation Strategy
Habitat Potential
Native Trout
High
Low
Habitat Integrity
Low
High
Protect Native Trout Habitat
Protect Coldwater Habitat
Little or No Coldwater Habitat
Restore Native Trout Habitat
Restore Coldwater Habitat
Little or No Coldwater Habitat
High Future Security
N
TROUT UNLIMITED
Seattle
OLYMPIA
Portland
Washington
Oregon
Idaho
HELENA
Spokane
Boise
Twin Falls
Pocatello
Bozeman
Logan
HARNEY BA
0 50 100 200 Kilometers


Future Security
Total Group Score
25 - 21 (High)
20 -16
15 - 11
10 - 5 (Low)
N
0
50
100
200 Kilometers
TROUT
UNLIMITED
Washington
Oregon
Idaho
Montana
Seattle
Portland
HARNEY BASIN


Habitat Integrity
Total Group Score
25 - 21 (High)
20 -16
15 - 11
10 - 5 (Low)
N
0 50 100 200 Kilometers
TROUT UNLIMITED
Washington
Oregon
Idaho
Montana
Seattle
OLYMPIA
Portland
HELENA
HARNEY BASIN



Total CSI Score
41 - 50 (High)
36 - 40
31 - 35
26 - 30
10 - 25 (Low)
N
0
50
100
200 Kilometers
TROUT UNLIMITED
Washington
Oregon
Idaho
Montana
Seattle
OLYMPIA
Portland
HELENA

v. 1 September 2011

Conservation Success Index:
Wild Trout – Interior Columbia River Basin
Subwatershed Scoring and Rule Set

Introduction:

The CSI – as originally developed - is an aggregate index comprised of four different component groups: Range-wide Condition; Population Integrity; Habitat Integrity; and Future Security. Each CSI group has five indicators that describe a specific component of each group. Each indicator is scored from 1 to 5 for each subwatershed, with a score of 1 indicating poor condition and a score of 5 indicating good condition. Indicator scores are then added to obtain the subwatershed condition for a Group, and Group scores are added for a CSI score for a subwatershed (Figure 1). CSI scores can then be summarized to obtain the general range of conditions within the historical or current distribution of the species.

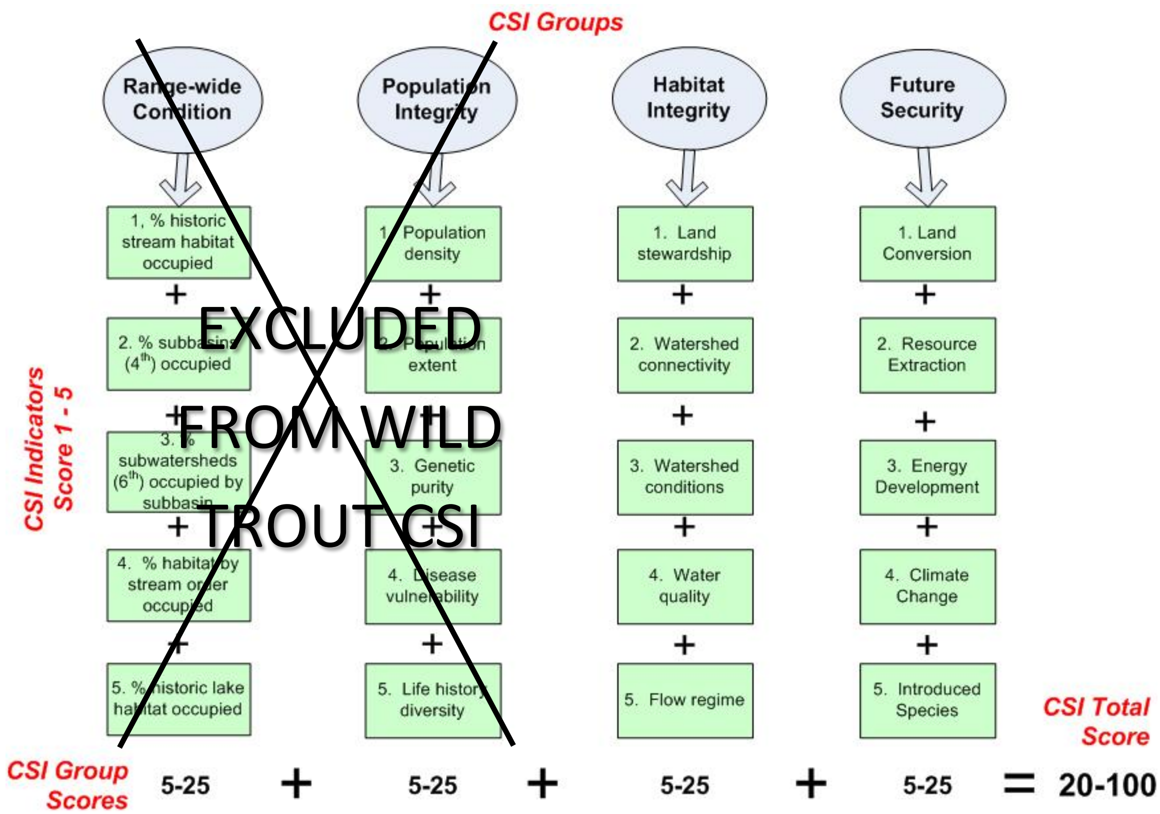


Figure 1. Each subwatershed is scored from 1 to 5 using 20 indicators within four main groups. Indicator scores are added per group to obtain an overall group score. Group scores are then added to obtain a composite CSI score for each subwatershed.

For the Wild Trout application the original CSI has been modified by only including the Habitat Integrity and Future Security indicators, thus resulting in total scores ranging from 10 (low) to

50 (high). Basic information on potential trout habitat suitability and native trout populations is also summarized, although it is not formally incorporated into a group of indicators and scored.

Below is an overview of wild trout habitat suitability potential, native fish population information, and Habitat Integrity and Figure Security CSI groups and the indicators within each group.

Wild Trout Habitat Suitability Potential*: Miles of potentially suitable wild trout habitat, defined as Good or Fair*.

Wild trout habitat suitability potential was modeled as a function of environmental variables known to influence coldwater streams and trout habitat. These variables were compared to stream segments (1:100,000 map scale) where trout populations are known to exist versus stream segments were trout were not believed to exist historically. Known trout populations and historical trout habitat were determined from rangewide cutthroat trout databases developed by recovery teams.[1-5] The presence of trout was predicted as a function of these environmental variables: mean annual flow (cfs) as a measure of stream size; mean annual velocity (f/s) as a measure of current velocity; stream slope (m/m); mean annual precipitation (cm / yr); mean annual August temperature in the entire watershed upstream of a stream segment; and percent forested land cover. Predictions were made using a Random Forest model[6] that was fit to all basins at once, and the model was then used to predict potential habitat suitability for all stream segments across the Interior West. The model had good predictive capability, owing to the fact that it described well stream segments where trout occur; in-sample model Area Under the Curve (AUC) of a Receiver Operating Characteristic (ROC)[7] plot was 0.867 indicating good model discrimination ability. Model predictions ranged from 0.0 to 1.0, and these were reclassified to Good = 0.66 – 1.0; Fair = 0.33 – 0.66; Poor = 0.0 – 0.33. In some cases, Good or Fair suitability designations in large rivers may indicate overwintering or migratory habitat.[8] This is a reflection of the fact that many larger rivers were designated has historical cutthroat trout habitat where fish may have used them for migration, overwintering, or for other life history functions.

Figure 1. Diagnostic measures describing the performance of the regression tree model predicting potential trout habitat suitability.

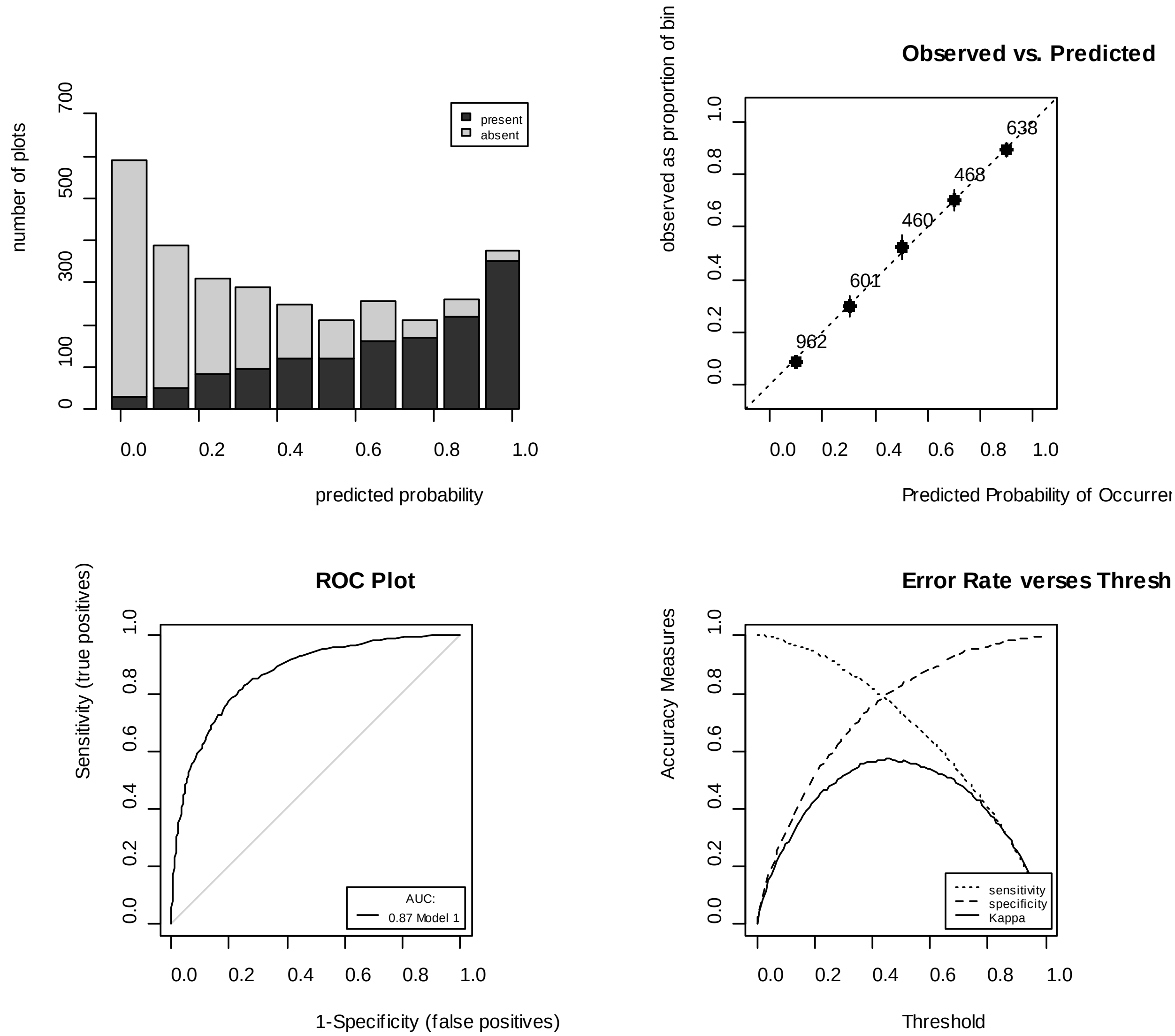
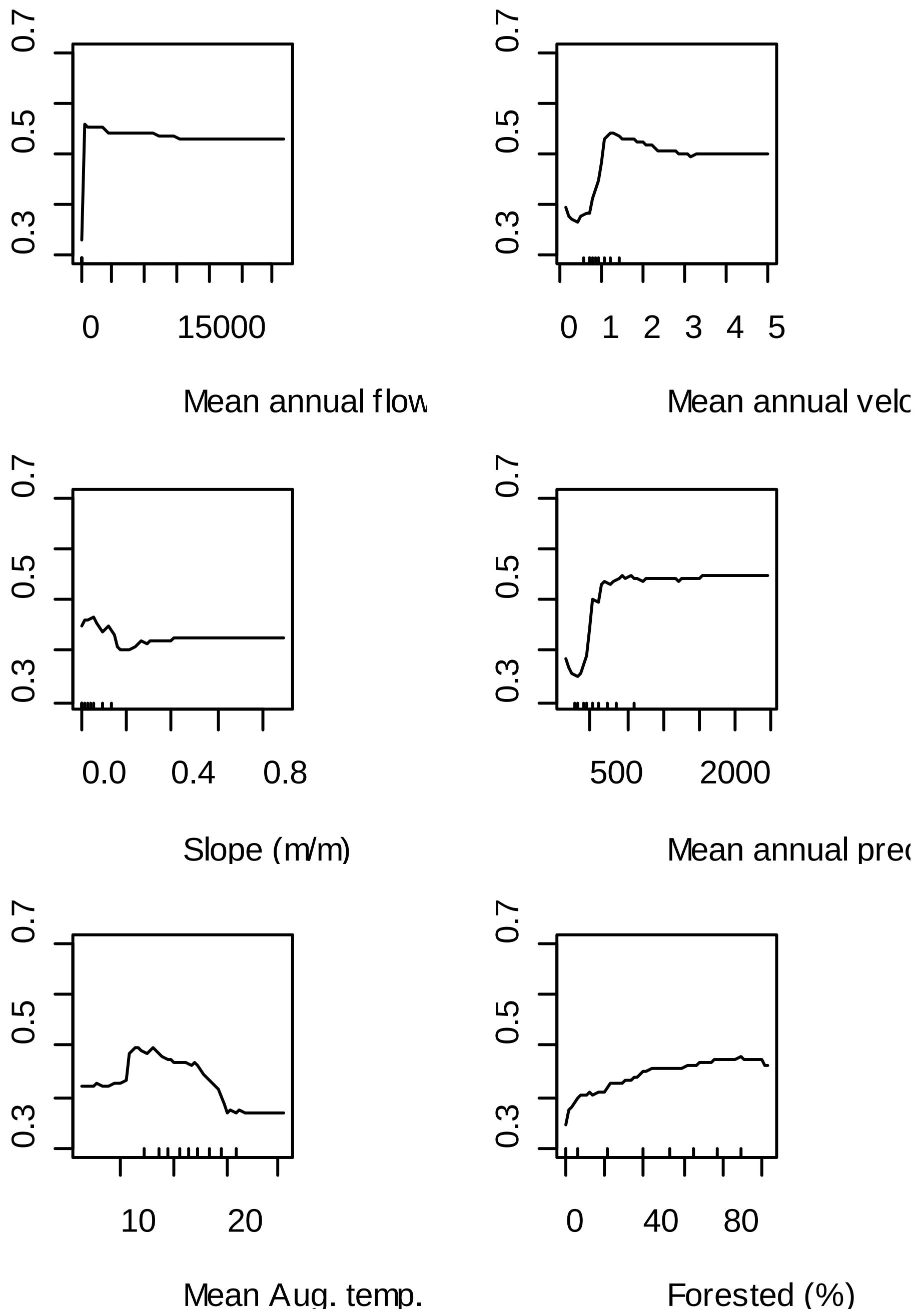


Figure 2. Plots showing how potential habitat suitability varies in relation to the different environmental variables (all other variables held and their mean value). Higher values indicate better trout habitat suitability.



Native Trout Occupied and Historical Habitat*: Miles of habitat currently and historically occupied by native trout populations*.

Native salmonid species included in the Interior Columbia calculations of currently and historically occupied native trout habitats: bull trout (current only)[9], westslope cutthroat trout (current and historical)[10], interior Columbia redband trout (current only)[9;11-14], and Yellowstone cutthroat trout (current and historical).[15]

Habitat Integrity*: Indicators for the integrity of aquatic habitats*.

Overview:

1. Land stewardship
2. Watershed connectivity
3. Watershed conditions
4. Water quality
5. Flow regime

Indicator: 1. Land stewardship.

Indicator Scoring:

Protected stream habitat	Subwatershed protection	CSI Score
none	any	1
1 – 9%	<25%	1
1 – 9%	≥25%	2
10 – 19%	<25%	2
10 – 19%	≥25%	3
20 – 29%	<50%	4
20 – 29%	≥50%	5
≥30%	any	5

Explanation: The percent of stream habitat AND percent subwatershed that is protected lands. Protected lands are federal or state lands with regulatory or congressionally-established protections, such as: federal or state parks and monuments, national wildlife refuges, wild and scenic river designations, designated wilderness areas, inventoried roadless areas on federal lands, Research Natural Areas, Areas of Critical Environmental Concern, others areas of special protective designations, or private ownership designated for conservation purposes (e.g., easements).

Rationale: Stream habitat and subwatersheds with higher proportions of protected lands typically support higher quality habitat than do other lands.

Data Sources: Protected areas data were compiled from the ESRI, Tele Atlas North American / Geographic Data Technology dataset on protected areas [16] and the U.S. Department of Agriculture, Forest Service's National Inventoried Roadless Areas dataset [17]. Stream habitat was determined using all streams in the National Hydrography Dataset Plus [18].

Indicator: 2. Watershed connectivity.

Indicator Scoring:

Number of stream/canal intersections	CSI Score
≥12	1
8 – 11	2
5 – 7	3
1 – 4	4
0	5

Explanation: The number of stream-canal intersections.

Rationale: Increased hydrologic connectivity provides more habitat area and better supports multiple life histories, which increases the likelihood of persistence [19]. Diversions, when they do not directly inhibit fish passage, can represent false movement corridors, cause fish entrainment, and act as population sinks [20;21].

Data Sources: Connectivity was determined using all streams was determined using all streams in the National Hydrography Dataset Plus [18].

Indicator: 3. Watershed condition.

Indicator Scoring:

Land conversion	CSI Score
≥30%	1
20 – 29%	2
10 – 19%	3
5 – 9%	4
0 - 4%	5

CSI score is downgraded 1 point if road density is ≥1.7 and <4.7 mi/square mile.
If road density is ≥4.7 mi/square mile it is downgraded 2 points.

Explanation: The percentage of converted lands in the subwatershed, and the density of roads.

Rationale: Habitat conditions are the primary determinant of persistence for most populations [22]. Converted lands are known to degrade aquatic habitats [23;24]. Road density is computed for the subwatershed; roads are known to cause sediment-related impacts to stream habitat [25-27]. Lee et al. [26] recognized 6 road density classifications as they related to aquatic habitat integrity and noted densities of 1.7 and 4.7 mi/mi^2 as important thresholds.

Data Sources: Converted lands were determined using the National Land Cover Database [28], with all Developed, Pasture/Hay, and Cultivated Crops land cover types considered to be converted lands. Road density is calculated from composite of BLM data for OR, WA, and ID[29;30] and US Census Bureau TIGER data for MT, NV, and WY.[31]

Indicator: 4. Water quality.

Indicator Scoring:

Miles 303(d) Streams	Agricultural Land	Number Active Mines	Number active oil/gas wells	Road mi/ Stream mi	CSI Score
>0	58-100%	≥10	≥400	0.5 – 1.0	1
	28-57%	7-9	300 - 399	0.25 – 0.49	2
	16-27%	4-6	200 - 299	0.10 - 0.24	3
	6-15%	1-3	50 - 199	0.05 – 0.09	4
	0-5%	0	0 - 49	0 – 0.04	5

Score for worst case.

Explanation: The presence of 303(d) impaired streams, percentage agricultural land, number of active mines, number of active oil and gas wells, and miles of road within 150 ft of streams in the subwatershed.

Rationale: Decreases in water quality, including reduced dissolved oxygen, increased turbidity, increased temperature, and the presence of pollutants, reduces habitat suitability for salmonids and other native fishes. Agricultural land can impact aquatic habitats by contributing nutrients and fine sediments, and deplete dissolved oxygen. Mining activity can deteriorate water quality through leachates and sediments. Oil and gas development is associated with road building, water withdrawals, and saline water discharge [32-34]. Roads along streams can also contribute large amounts of fine sediments that smother benthic invertebrates, embed spawning substrates, and increase turbidity [35;36].

Data Sources: 303(d) listed streams data is a composite of OR (2004/2006),[37] WA (2008),[38] ID (2008, 2002),[39;40] WY (2010),[41] MT (2010),[42] and NV (2006)[43] data. The National Land Cover Database [28] was used to identify agricultural lands; Hay/Pasture and Cultivated Crops were defined as agricultural land. Active mines were identified by using the Mineral Resources Data System [44]. Active oil and gas wells from Wyoming Oil and Gas Conservation Commission [45]. Road density within a 150 ft buffer was computed using BLM data for OR, WA, and ID[29;30] and US Census Bureau TIGER data for MT, NV, and WY[31] and the National Hydrography Dataset Plus [18].

Indicator: 5. Flow regime.

Indicator Scoring:

Number of dams	Miles of Canals	Storage (acre-ft)/stream mile	CSI Score
≥5	≥20	≥2,500	1
3 – 4	10 – 19.9	1,000 – 2,499	2
2	5 – 9.9	250 – 999	3
1	1 – 4.9	1- 249	4
0	0 – 0.9	0	5

Score for worst case.

Explanation: Number of dams, miles of canals, and acre-feet of reservoir storage per perennial stream mile.

Rationale: Natural flow regimes are critical to proper aquatic ecosystem function [46]. Dams, reservoirs, and canals alter flow regimes [47]. Reduced or altered flows reduce the capability of watersheds to support native biodiversity and salmonid populations.

Data Sources: The National Inventory of Dams [48] was the data source for dams and their storage capacity. Data on canals were obtained from the National Hydrography Dataset Plus [18]. Perennial streams were obtained from the National Hydrography Dataset Plus [18].

Future Security *Indicators for the future security of populations and aquatic habitats.*

Overview:

1. Land conversion

2. Resource extraction
3. Energy development
4. Climate change
5. Introduced species

Indicator: 1. Land conversion.

Indicator Scoring:

Land Vulnerable to Conversion	CSI Score
81 – 100%	1
61 – 80%	2
41 - 60%	3
21 - 40%	4
0 – 20%	5

Explanation: The potential for future land conversion for urban or exurban purposes. Public land, lands currently converted, exceptionally productive forest types suitable for industrial forestry, or private lands encumbered by conservation easements are not available for conversion. Lands outside of Oregon Urban Growth Boundaries are available for vineyard conversion, but not urban conversion.

Rationale: Conversion of land from its natural condition will reduce aquatic habitat quality and availability [49;50].

Data Sources: Urban and exurban development in 2030 using the Spatially Explicit Regional Growth Model v3 for the US Forests on the Edge project.[51] Oregon Urban Growth Boundaries from OR Dept of Land Conservation and Development.[52]

Indicator: 2. Resource extraction.

Indicator Scoring:

Forest management	Hard Metal Mine Claims	CSI Score
51-100%	51 -100%	1
26 – 50%	26-50%	2
11 – 25%	11-25%	3
1 – 10%	1 – 10%	4
0%	0%	5

Score for worst case.

Explanation: Percentage of subwatershed available for industrial timber production and the percent of subwatershed with hard metal mining claims (assuming an average of 20 acres per claim) outside of protected areas. Protected lands were removed from availability and include: federal or state parks and monuments, national wildlife refuges, wild and scenic river designations, designated wilderness areas, inventoried roadless areas on federal lands, Research Natural Areas, Areas of Critical Environmental Concern, others areas of special protective designations, or private ownership designated for conservation purposes.

Rationale: Productive forest types have a higher likelihood of being managed for timber production than unproductive types, and, hence, future logging poses a future risk to aquatic habitats and fishes [25]. Areas with hard metal claims pose a future risk to mining impacts than areas without claims. Claims indicate areas with potential for hard mineral mining, and mining can impact aquatic habitats and fishes [53].

Data Sources: Timber management potential identifies productive forest types using the existing vegetation type in the Landfire dataset [54]. The number of mining claims was determined using Bureau of Land Management data [55], and each claim was assumed to potentially impact 20 acres. Protected areas data were compiled from the ESRI, Tele Atlas North American / Geographic Data Technology dataset on protected areas [16] and the U.S. Department of Agriculture, Forest Service's National Inventoried Roadless Areas dataset [17].

Indicator: 3. Energy Development.

Indicator Scoring:

Leases or reserves	New Dams 4th	New Dams 6th	CSI Score
51-100%	≥4	≥1	1
26 – 50%	3		2
11 – 25%	2		3
1 – 10%	1		4
0%	0		5

Score for worst case

Explanation: The acreage of oil, gas, and coal reserves and the number of dam sites located for potential development outside of protected areas within each subbasin and subwatershed.

Rationale: Increased resource development will increase road densities, modify natural hydrology, and increase the likelihood of pollution to aquatic systems. Changes in natural flow regimes associated with dams are likely to reduce habitat suitability for native salmonids and increase the likelihood of invasion by non-native species[56]. If lands are protected then the watersheds will be less likely to be developed.

Data Sources: Oil and gas leases and agreements from BLM Geocommunicator [57]. Potential dam sites are based on Idaho National Laboratory (INL) hydropower potential data [58]. Protected areas data were compiled from the ESRI, Tele Atlas North American / Geographic Data Technology dataset on protected areas [16] and the U.S. Department of Agriculture, Forest Service's National Inventoried Roadless Areas dataset [17].

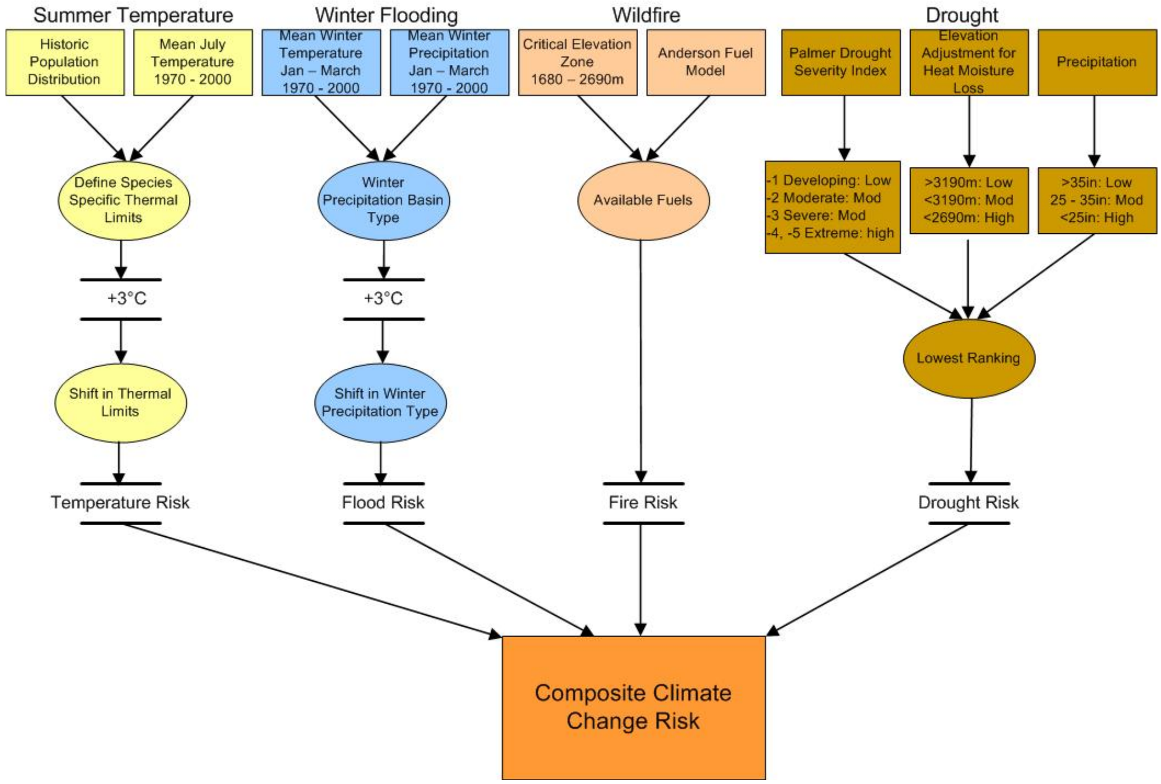
Indicator: 4. Climate change.

Indicator Scoring:

TU Climate Change Analysis	
Climate Risk Factors	**CSI Score**
High, High, Any., Any	1
High, Any, Any, Any	2
Mod., Mod., Mod, (Mod or Low)	3
Mod, Mod, Low, Low	4
Low, Low, Low, (Mod or Low)	5

Explanation: Climate change is based on TU Climate Change analysis, which focuses on 4 identified risk factors related to climate change:

a. Increased Summer Temperature: loss of lower-elevation (higher-stream order) habitat impacts temperature sensitive species
b. Uncharacteristic Winter Flooding: rain-on-snow events lead to more and larger floods
c. Uncharacteristic Wildfire: earlier spring snowmelt coupled with warmer temperatures results in drier fuels and longer burning, more intense wildfire
d. Drought: moisture loss under climate warming will overwhelm any gains in precipitation and lead to higher drought risk



Each of the four factors is ranked as low, moderate, or high. Increased summer temperature due to climate change was modeled as a 3°C increase. Uncharacteristic winter flooding can result from basins transitioning from snow dominated to rain-on-snow dominated with increased winter flooding. Uncharacteristic wildfires result from changes in climate and fire fuels. Drought risk is based on the Palmer Drought Severity Index, but was adjusted for elevation and precipitation.

Rationale: Climate change is likely to threaten most salmonid populations because of warmer water temperatures, changes in peak flows, and increased frequency and intensity of disturbances such as floods and wildfires [59;60]. A 3°C increase in summer temperature has the potential to impact coldwater species occupying habitat at the edge of their thermal tolerance. Increased winter flooding can cause local populations to be extirpated. Wildfire can change aquatic habitats, flow regimes, temperatures, and wood inputs that are important to salmonids [61]. Drought is expected to reduce water availability [62;63] and the availability of aquatic habitat. These risks are further discussed by Williams et al.[59]

Data Sources: Temperature and precipitation data were obtained from the PRISM Group[64]. Elevation data was obtained from the National Elevation Dataset [65], and LANDFIRE data for the Anderson Fire Behavior Fuel Model 13 [54] was used as input for wildfire risk. The Palmer Drought Severity Index was used for drought risk [66], but was adjusted for elevation (elevations above 2690 have lower risk [63]) and the deviation from mean annual precipitation (areas with more precipitation on average have lower risk).

Indicator: 5. Introduced species.

Indicator Scoring:

If introduced species have been documented in a subwatershed

Present in 4th	Present in 6th	Road Density	CSI Score
Yes	Yes	Any	1
Yes	No	>4.7	2
Yes	No	1.7 - 4.7	3
Yes	No	<1.7	4
No	No	Any	5

Score worst case.

If introduced species have not been documented in a subwatershed

Present in 4th	Road Density	CSI Score
Yes	>4.7	1
Yes	3.7 – 4.7	2
Yes	2.7 – 3.7	3
Yes	<2.7	4
No	any	5

Score worst case.

If introduced species have not been documented in a subwatershed or subbasin

Road Density	CSI Score
>4.7	1
3.7 – 4.7	2
2.7 – 3.7	3
1.7 – 2.7	4
<1.7	5

Score worst case.

Explanation: The presence of introduced, injurious species in a subbasin and subwatershed and road density. Road density is the length of road per subwatershed area, and represents the potential for future introduction of non-native species into the subwatershed.

Rationale: Introduced species can reduce native fish populations through predation, competition, hybridization, and the introduction of non-native parasites and pathogens [67]. In the absence of data on presence of non-native species in a subwatershed or subbasin, road density can be used as a surrogate for risk of non-native fish introductions by perpetrators [68].

Data Sources: Road density was calculated using BLM data for OR, WA, and ID[29;30] and US Census Bureau TIGER data for MT, NV, and WY[31].

References

1. U.S.Fish and Wildlife Service, "Lahontan cutthroat trout 5-year review: summary and evaluation" (Nevada Fish and Wildlife Office, U.S. Fish and Wildlife Service, Reno, Nevada, 2009).

2. B. E. May and S. Albeke, "Range-wide status of Bonneville cutthroat trout (*Oncorhynchus clarki utah*): 2004" *Report No. Bonneville Cutthroat Trout Status Update Interagency Coordination Workgroup, Publication Number 05-02* (Utah Division of Wildlife Resources, Salt Lake City, Utah, 2005).

3. Greenback cutthroat trout recovery team, "Greenback cutthroat trout recovery plan" (U.S. Fish and Wildlife Service, Denver, Colorado, 1998).

4. C. L. Hirsch, S. E. Albeke, T. P. Nesler, "Range-wide status of Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*): 2005" *Report No. Colorado River Cutthroat Trout Conservation Team* 2006).

5. B. E. May, W. Urie, B. B. Shepard, Yellowstone Cutthroat Trout Interagency Coordination Group, "Range-wide status of Yellowstone cutthroat trout (Oncorhynchus clarki bouvieri): 2001" (Yellowstone Cutthroat Trout Interagency Coordination Group, Boise, Idaho, 2003).

6. L. Breiman, "Random forests", *Machine Learning* 45, 5-32 (2001).

7. D. W. Hosmer and S. Lemeshow, Applied logistic regression (John Wiley & Sons, Inc., New York, ed. second, 2000).

8. A. J. Carlson and F. J. Rahel, "Annual intrabasin movement and mortality of adult Bonneville cutthroat trout among complementary riverine habitats", *Trans.Amer.Fish.Soc.* 139, 1360-1371 (2010).

9. StreamNet GIS Data. "StreamNet generalized species distributions (July 2010)". 2011. Portland, OR, Pacific States Marine Fisheries Commission.

10. B. E. May, "Westslope cutthroat trout status update summary 2009" (Wild Trout Enterprises, LLC, Bozeman, Montana, 2009).

11. Johnson, G. "NDOW redband trout streams 2006". 2006. Reno, NV, Nevada Division of Wildlife.

12. Washington Department of Fish and Wildlife. "Anadromous and resident fish distribution (1:24,000)". 2008. Olympia, WDFW.

13. Oregon Department of Fish and Wildlife. "Oregon rainbow/redband distribution v9". 2009. Salem, Oregon Department of Fish and Wildlife.

14. Schill, D. J. "Redband trout likely distribution". 2010. Nampa, ID, Idaho Department of Fish and Game.

15. B. E. May, S. E. Albeke, T. Horton, "Range-wide status assessment for Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*): 2006" (Yellowstone Cutthroat Trout Interagency Coordination Group, 2007).

16. ESRI. "Protected areas (1:100,000)". 2004. Redlands, California, U.S. Tele Atlas North America, Inc. / Geographic Data Technology, Inc., ESRI.

17. USDA Forest Service. "National inventoried roadless areas (IRAs)". 2008. Salt Lake City, Utah, Geospatial Service and Technology Center, U.S. Department of Agriculture, Forest Service. http://fsgeodata.fs.fed.us/clearinghouse/other_fs/other_fs.html.

18. USEPA and USGS. "National Hydrography Dataset Plus - NHDPlus (1:100,000 scale)". 2005. Sioux Falls, South Dakota, U.S. Environmental Protection Agency and U.S. Geological Survey. http://www.horizon-systems.com/nhdplus/.

19. W. T. Colyer, J. L. Kershner, R. H. Hilderbrand, "Movements of fluvial Bonneville cutthroat trout in the Thomas Fork of the Bear River, Idaho-Wyoming", *N.Am.J.Fish.Manage.* 25, 954-963 (2005).

20. A. J. Schrank and F. J. Rahel, "Movement patterns in inland cutthroat trout (*Oncorhynchus clarki utah*): management and conservation implications", *Can.J.Fish.Aquat.Sci.* 61, 1528-1537 (2004).

21. J. J. Roberts and F. J. Rahel, "Irrigation canals as sink habitat for trout and other fishes in a Wyoming drainage", *Trans.Amer.Fish.Soc.* 137, 951-961 (2008).

22. A. L. Harig, K. D. Fausch, M. K. Young, "Factors influencing success of greenback cutthroat trout translocations", *N.Am.J.Fish.Manage.* 20, 994-1004 (2000).

23. B. B. Shepard, R. Spoon, L. Nelson, "A native westslope cutthroat trout population responds positively after brook trout removal and habitat restoration", *Intermount.J.Sci.* 8, 191-211 (2002).

24. S. M. White and F. J. Rahel, "Complementation of habitats for Bonneville cutthroat trout in watersheds influenced by beavers, livestock, and drought", *Trans.Amer.Fish.Soc.* 137, 881-894 (2008).

25. G. S. Eaglin and W. A. Hubert, "Effects of logging and roads on substrate and trout in streams of the Medicine Bow National Forest, Wyoming", *N.Am.J.Fish.Manage.* 13, 844-846 (1993).

26. D. C. Lee, J. R. Sedell, B. E. Rieman, R. F. Thurow, J. E. Williams, "Broadscale assessment of aquatic species and habitats" in *An assessment of ecosystem components in the Interior Columbia Basin and portions of the Klamath and Great Basins: Volume III*, T. M. Quigley and S. J. Arbelbide, Eds. (USDA Forest Service, General Technical Report PNW-GTR-405, Portland, Oregon, 1997).

27. T. F. Waters, Sediment in streams: sources, biological effects, and control (American Fisheries Society Monograph 7, Bethesda, Maryland, 1995).

28. USGS. "National Land Cover Database". 2001. Sioux Falls, South Dakota, U.S. Geological Survey.

29. US Bureau of Land Management. "Ground Transportation Roads - Oregon and Washington". 2009. Oregon BLM State Office. Continually updated, accessed December 2008.

30. US Bureau of Land Management. "Ground Transportation Roads - Idaho". 2004. Boise, ID, Idaho BLM State Office.

31. USGS. "All Roads in the Western United States (2000 TIGER) (1:100,000)". 2008. http://sagemap.wr.usgs.gov/HumanFootprint.aspx.

32. C. Murray-Gulde, J. E. Heatley, T. Karanfil, J. H. Jr. Rodgers, J. E. Myers, "Performance of a hybrid reverse osmosis-constructed wetland treatment system for brackish oil field produced water", *Water Res.* 37, 705-713 (2003).

33. M. Cakmakce, N. Kayaalp, I. Koyuncu, "Desalination of produced water from oil production fields by membrane processes", *Desalination* 222, 176-186 (2008).

34. C. A. Rice, M. S. Ellis, J. H. Jr. Bullock, "Water co-produced with coalbed methane in the Powder River Basin, Wyoming: preliminary compositional data" *Report No. Open-File Report 00-372* (U.S. Department of the Interior, U.S. Geological Survey, Denver, Colorado, 2000).

35. D. S. Lloyd, "Turbidity as a water quality standard for salmonid habitats in Alaska", *N.Am.J.Fish.Manage.* 7, 34-45 (1987).

36. R. J. Davies-Colley and D. G. Smith, "Turbidity, suspended sediment, and water clarity: a review", *J.Am.Water Resour.Assoc.* 37, 1085-1101 (2001).

37. Oregon Department of Environmental Quality, W. Q. D. "Oregon 2004/2006 Integrated Report on Water Quality". 2007. Portland, OR.

38. Department of Ecology. "Washington State's Water Quality Assessment [303(d)]". 2008. 2009. Olympia, Washington State Department of Ecology.

39. IDEQ. "Streams of Idaho: 305(b) & 303(d) integrated report - water quality - 2002". 2002. Boise, Idaho, Idaho Department of Environmental Quality. http://www.deq.state.id.us/water/data_reports/surface_water/monitoring/integrated_report.cfm.

40. IDEQ. "Streams of Idaho: 305(b) & 303(d) integrated report - water quality - 2008". 2010. Boise, Idaho, Idaho Department of Environmental Quality.

41. Wyoming DEQ. "Wyoming Water Quality Assessment and Impaired Waters List (2010 Integrated 305(b) and 303(d) Report)". 2010. Cheyenne, WY, Wyoming Department of Environmental Quality.

42. MT DEQ. "Montana 2010 Water Quality Integrated Report". 2010. Helena, MT, Montana Department of Environmental Quality.

43. NV DEP. "Nevada's 2006 303(d) Impaired Waters List". 2006. Carson City, NV, Nevada Division of Environmental Protection.

44. USGS. "Mineral Resources Data System (MRDS) (Active)". (2005). 2008. Reston, Virginia, U.S. Geological Survey. http://tin.er.usgs.gov/mrds/.

45. Wyoming Oil and Gas Conservation Commission. "Wyoming Active Oil and Gas Wells". 9.

46. N. L. Poff et al., "The natural flow regime", *BioScience* 47, 769-784 (1997).

47. A. C. Benke, "A perspective on America's vanishing streams", *J.N.Am.Benthol.Soc.* 9, 77-88 (1990).

48. USACE. "National Inventory of Dams". 2008. U.S. Army Corps of Engineers. http://crunch.tec.army.mil/nidpublic/webpages/nid.cfm.

49. S. E. Stephens et al., "Predicting risk of habitat conversion in native temperate grasslands", *Conserv.Biol.* 22, 1320-1330 (2008).

50. C. L. Burcher, H. M. Valett, E. F. Benfield, "The land-cover cascade: relationships coupling land and water", *Ecology* 88, 228-242 (2007).

51. Theobald, D. "bhc2030 v1". 2004. On file with: David M. Theobald, Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO 80526.

52. OR Department of Land Conservation and Development. "Oregon Urban Growth Boundaries". 2009. Salem, Oregon Department of Land Conservation and Development.

53. P. H. Rahn, A. D. Davis, C. J. Webb, A. D. Nichols, "Water quality impacts from mining in the Black Hills, South Dakota, USA", *Environmental Geology* 27, 38-53 (1996).

54. USFS. "LANDFIRE". (Rapid Refresh). 2008. Wildland Fire Leadership Council and U.S. Forest Service. http://www.landfire.gov/.

55. Hyndman, P. C. and Campbell, H. W. "BLM mining claim recordation system: mining claim density". 1996. Fort Collins, Colorado, Open-File Report 99-325. Natural Resource Ecology Labaoratory, U.S. Geological Survey.

56. K. D. Fausch, "A paradox of trout invasions in North America", *Biol.Invasions* 10, 685-701 (2008).

57. USBLM. "Geocommunicator". 2008. USBLM and USFS. http://www.geocommunicator.gov/GeoComm/index.shtm.

58. INL. "Hydropower Resource Assessment". 2004. Idaho Falls, Idaho, Idaho National Laboratory.

59. J. E. Williams, A. L. Haak, H. M. Neville, W. T. Colyer, "Potential consequences of climate change to persistence of cutthroat trout populations", *N.Am.J.Fish.Manage.* 29, 533-548 (2009).

60. J. E. Williams, A. L. Haak, H. M. Neville, W. T. Colyer, N. G. Gillespie, "Climate change and western trout: strategies for restoring resistance and resilience in native populations" in *Wild Trout IX: Sustaining wild trout in a changing world*, R. F. Carline and C. LoSapio, Eds. (Wild Trout Symposium, Bozeman, Montana, 2007).

61. J. B. Dunham, M. K. Young, R. E. Gresswell, B. E. Rieman, "Effects of fire on fish populations: landscape perspectives on persistence of native fishes and nonnative fish invasions", *Forest Ecology and Management* 178, 183-196 (2003).

62. M. P. Hoerling and J. Eischeid, "Past peak water in the Southwest", *Southwest Hydrology* 6, 18-19,35 (2007).

63. A. L. Westerling, H. G. Hidalso, D. R. Cayan, T. W. Swetnam, "Warming and earlier spring increases western U.S. forest wildfire activity", *Science* 313, 940-943 (2006).

64. PRISM Group. "PRISM 800m Normals (1971 - 2000)". 2008. Corvallis, Oregon, Oregon State University. http://www.prism.oregonstate.edu/.

65. USGS. "National Elevation Dataset (30m) (1:24,000)". 2008. Sioux Falls, SD, USGS EROS Data Center. http://ned.usgs.gov/.

66. W. C. Palmer, "Meteorological drought" *Report No. Research Paper No. 45* (U.S. Weather Bureau, 1965).

67. K. D. Fausch, B. E. Rieman, M. K. Young, J. B. Dunham, "Stategies for conserving native salmonid populations at risk from nonnative fish invasions: tradeoffs in using barriers to upstream movement" *Report No. General Technical Report RMRS-GTR-174* (U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado, 2006).

68. F. J. Rahel, "Unauthorized fish introductions: fisheries management of the people, for the people, or by the people" in *Propagated fish in resource management*, M. J. Nickum, P. M. Mazik, J. G. Nickum, D. D. MacKinlay, Eds. (American Fisheries Society Symposium 44, Bethesda, Maryland, 2004).